Renewable and Sustainable Energy Reviews 15 (2011) 2176–2184

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review of the factors affecting operation and efficiency of photovoltaic based electricity generation systems

Mehmet Emin Meral*, Furkan Dinçer

Yuzuncu Yil University, Department of Electrical and Electronics Engineering, Van, Turkey

ARTICLE INFO

Article history:
Received 9 July 2010
Accepted 24 January 2011

Keywords:
Photovoltaics
Efficiency of PV systems

ABSTRACT

One of the most popular techniques of renewable energy generation is the installation of photovoltaic (PV) systems using sunlight to generate electrical power. There are many factors that affecting the operation and efficiency of the PV based electricity generation systems, such as PV cell technology, ambient conditions and selection of required equipment. There is no much study that presents all factors affecting efficiency and operation of the entire PV system, in the literature. This paper provides a detailed review of these factors and also includes suggestions for the design of more efficient systems. The presented detailed overview will be useful to people working on theory, design and/or application of photovoltaic based electricity generation systems.

Contents

1. Introduction

Sunlight is the source of solar energy regarded as an alternative source of energy along with other renewable energy sources such as hydrogen and wind. Solar energy is a vital that can make environment friendly energy more flexible, cost effective and commercially widespread. Therefore, it is widely used today in many applications such as water heating system, satellite power system and electricity power generation and others [1].

One of the promising applications of renewable energy technology is the installation of photovoltaic (PV) systems using sunlight to generate electrical power without emitting pollutants and requiring no fuel. The main countries eader in PV market are Spain,

* Corresponding author. Tel.: +90 4322251024; fax: +90 4322251730.
E-mail addresses: emeral@yyu.edu.tr (M.E. Meral), furkandincer@yyu.edu.tr (F. Dinçer).

1364-0321/$ – see front matter
doi:10.1016/j.rser.2011.01.010

Germany, USA, Japan, and China [2]. The efforts of these countries are summarized as follows:

- Spain became the PV market leader, with 2.6 GW of new grid-tied installations [3]. As a result, the global PV market has grown by around 5600 MW. This enormous 100% increase compared with the 2007. But, with a cap of 500 MW in 2009, it also means that the Spanish market will decrease in size by at least 80% (or more than 2100 MW) this year [4]. Spain's low ranking here means that the country still has a long way to go to fully benefit from this type of energy, and that greater use should be made of solar power in the design and construction of houses [5].
- The cumulative installed PV power in Germany increased to 5.3 GW by the end of 2008. Annually installed power in 2008 was approximately 1500 MW. Germany remained the one leading PV market worldwide just after Spain. More than a third of the global cumulative PV power installed is located in Germany. Although the absolute market figures keep growing in Germany, the market share of Germany in Europe has been shrinking during the last year as markets like Spain and Italy finally followed the successful German path [6].
- The third largest PV market was the USA with 624 MW of PV installations in 2006, and a cumulative installed PV capacity totaling 1.45 GW [7].
- Japan is an important market player with respect to both the global supply, i.e. its domestic PV industry, and the demand for PV, i.e. its strong domestic market. This country was the worldwide market leader until the end of 2004 and after this year changed its first place in favour of Germany [8]. The cumulative installed PV capacity in Japan reached 1.71 GW in 2006 [7].
- China's PV industry is growing faster than perhaps any other country in the world [9]. At present, the PV industry of China has a huge development in past 10 years. For example, the yield of Chinese PV in 2007 is more than 1200 MW, and which has share of 35% in whole world, which ranks the first in the world [10]. PV power generation will play a significant role in China's future energy supply [11].

Reliable knowledge on the PV systems is essential for efficiency, correct product selection, and accurate prediction of the electricity production. The efficiency, defined as the ratio of the power generated to the solar irradiance incident on the PV panel, is an important factor affecting the system design [12].

A PV module or PV panel is a packaged interconnected assembly of PV cells. The PV module, known more commonly as the solar panel, is then used as a component in a larger PV system to offer electricity for commercial and residential applications [13]. Another term, PV array consists of a number of individual PV modules connected together (serial or parallel) to give a suitable current and voltage output.

Although the installation cost of PV system is high but the advantage of PV source is free. The major problem for the PV cell is that it has low efficiency if the position and usage of the PV cell is not suitable. It needs maximum sunlight to produce the highest efficiency. Furthermore, there are many factors that affecting the operation and efficiency of PV based electricity generation system, such as PV cell technology, ambient conditions and selection of used equipment.

Up to the present, most of the studies have been interested in only specific factors affecting efficiency of PV panels and/or PV systems. There is no much study that presents all factors affecting efficiency and operation of the entire PV system, in the literature. This paper focuses on almost all of these factors. Firstly, an overview of the PV cells/panels and PV electricity generation systems are presented. Then, the affects of PV cell technology and ambient conditions are described. The selection criterion of required equipment such as battery and power electronic controllers also presented. Power quality requirements for the grid-connected systems are also mentioned.

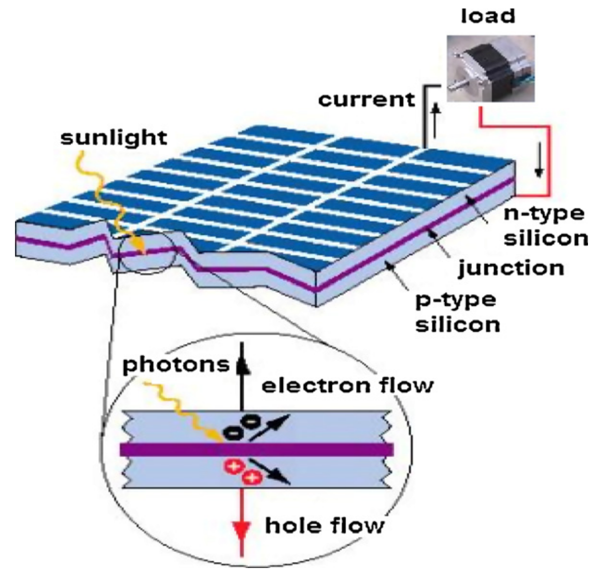

Fig. 1. The photovoltaic effect in PV cells [15].

2. Overview of PV cells

2.1. Structure and operation of PV cells

PV cells/modules are designed for outdoor use in such harsh conditions as marine, tropic, arctic, and desert environments. The choice of the PV material can have important effects on system design and performance. Both the composition of the material and its atomic structure are influential. PV materials include silicon, gallium arsenide (GaAs), copper indium diselenide (CuInSe2), cadmium telluride (CdTe), indium phosphide, and many others. The atomic structure of a PV cell can be monocrystal, multiycrystalline, or amorphous [14].

To understand the operation of a PV cell, it is need to consider both the nature of the material and the nature of sunlight. PV cells consist of two types of material; p-type silicon and n-type silicon. Light of certain wavelengths is able to ionize the atoms in the silicon and the internal field produced by the junction separates some of the positive charges (holes) from the negative charges (electrons) within the PV device. The holes are swept into the p-layer and the electrons are swept into n-layer. Although these opposite charges are attracted to each other, most of them can only recombine by passing through an external circuit outside the material because of the internal potential energy barrier. Therefore if a circuit as shown in Fig. 1 is composed, power can be produced from the cells under illumination, since the free electrons have to pass through the load to recombine with the positive holes [15].

2.2. Characteristics of a PV cell

As was mentioned above, PV cells are made of semi-conductor materials, usually silicon, and are specially treated to form an electric field with positive on one side (backside) and negative on the other side, facing the sunlight. When solar energy (photons) hits the PV cell, electrons are knocked loose from the atoms in the semiconductor material, creating electron–hole pairs. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons are captured in the form of

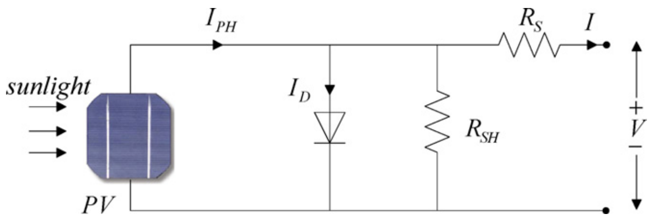

Fig. 2. Circuit diagram of single PV cell.

electric current, called photocurrent, I_{PH}. As can be understood from this description, during darkness the PV cell is not active and works as a diode (p–n junction) that does not produce any current or voltage. However, if it is connected to an external, large voltage supply, it generates a current, called the diode or dark current, I_D. A PV cell is usually represented by an electrical equivalent one-diode model, shown in Fig. 2. This circuit can be used for an individual PV cell, a PV module consisting of a number of cells, or an PV array consisting of several modules [14].

As shown in Fig. 2, the model contains a current source, I_{PH}, one diode, and a series resistance R_S, which represents the resistance inside each cell. The diode has also an internal shunt resistance. The net current is the difference between the photocurrent I_{PH}, and the normal diode current I_D, given by [14]:

$$I = I_{PH} - I_D - \frac{V + IR_S}{R_{SH}} = I_{PH} - I_0\left[\exp\left(\frac{e(V + IR_S)}{kT_C}\right) - 1\right] - \frac{V + IR_S}{R_{SH}} \quad (1)$$

It should be noted that the shunt resistance is usually much bigger than a load resistance, whereas the series resistance is much smaller than a load resistance. Therefore, by ignoring these two resistances, the net current is the difference between the photocurrent I_{PH}, and the normal diode current I_D, given by [14]:

$$I = I_{PH} - I_D = I_{PH} - I_0\left[\exp\left(\frac{eV}{kT_C}\right) - 1\right] \quad (2)$$

where k is Boltzmann's gas constant, 1381×10^{-23} J/K; T_C is absolute temperature of the cell (K); e is electronic charge, 1602×10^{-19} J/E; V is voltage imposed across the cell (V); I_0 is dark saturation current, which depends strongly on temperature (A).

Another important equation is for open circuit voltage V_{OC}:

$$V_{OC} = \frac{kT}{q}\ln\left(\frac{I_{PH}}{I_0} + 1\right) \approx \frac{kT}{q}\ln\left(\frac{I_{PH}}{I_0}\right) \quad (3)$$

Fig. 3 shows an I–V characteristic of PV module together with the power curve [16].

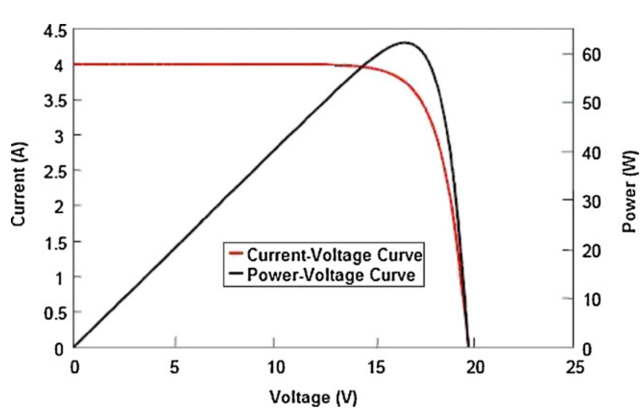

Fig. 3. *I–V* characteristic of a crystalline silicon PV module with the variation of power [16].

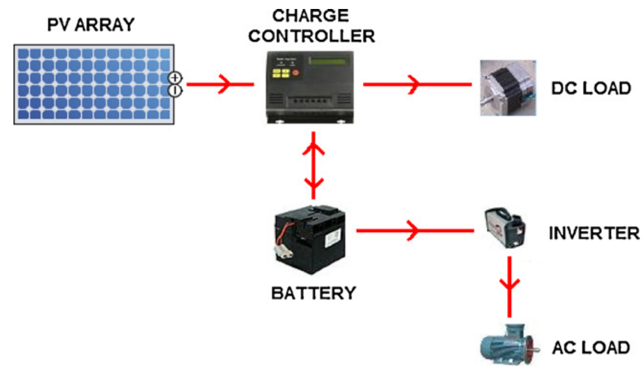

Fig. 4. Schematic diagram of a stand-alone PV application.

3. PV systems

There are two major PV based electricity generation systems. These are:

- Stand-alone PV system.
- Grid-connected PV system.

3.1. Stand-alone PV system

Many PV systems operate in a stand-alone mode. Such systems consist of a PV generator, energy storage (for example a battery), charge controllers, AC and DC consumers and power conditioners. Per definition, a stand-alone system involves no interaction with a utility grid. A PV generator can contain several PV arrays, while each array is composed of several PV modules. The battery bank stores energy when the power supplied by the PV modules exceeds load demand and releases it backs when the PV supply is insufficient. The load for a stand-alone PV system can be of many types, both DC (television, lighting, etc.) and AC (electric motors, heaters, etc.). The power conditioner system (inverter, etc.) provides an interface between all the elements of the PV system, giving protection and control [17] (Fig. 4).

3.2. Grid-connected PV system

In the grid-connected PV system, PV systems are connected to the local electricity network. This means that, during the day, the electricity generated by the PV system can either be used immediately (which is suitable for systems installed in offices, other commercial buildings, and industrial applications) or be sold to one of the electricity supply companies (which is more common for domestic systems, where the occupier may be out during the day) [14].

In the evening, when the PV system is unable to provide the electricity required, power can be bought back from the local network. This type PV system does not need to include battery storage. The block diagram of a grid-connected system is shown in Fig. 5 [14].

3.3. System equipments

Equipments that related with PV systems described above, include batteries, charge controllers, inverters, and maximum power trackers.

3.3.1. Batteries

Batteries accumulate excess energy created by PV system and store it to be used at night or when there is no other energy input. Batteries can discharge rapidly and yield more current that the charging source can produce by itself, so pumps or motors can be

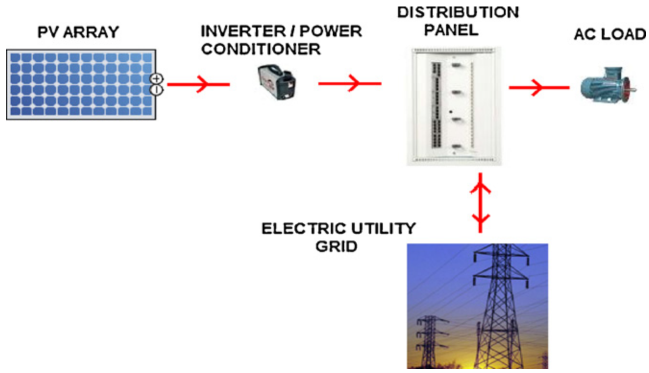

Fig. 5. Schematic diagram of a grid-connected system.

run intermittently. Different chemicals can be combined to produce batteries. Some combinations are low cost but low power also, others can store huge power at huge prices. The main types of batteries available today include lead-acid, nickel cadmium, nickel hydride, and lithium [18]. Deep-cycle lead-acid batteries are the most commonly used. These can be flooded or valve-regulated batteries and are commercially available in a variety of sizes. Flooded (or wet) batteries require greater maintenance but, with proper care, can last longer, whereas valve-regulated batteries require less maintenance [14].

Batteries are used mainly in stand-alone PV systems to store the electrical energy produced during the hours when the PV system covers the load completely and there is excess or when there is sunshine but no load is required. Additionally, batteries are required in such a system because of the fluctuating nature of the PV system output [14].

3.3.2. *Charge controllers*

The main task of PV charge controller (regulator) is to charge the battery and to protect it from deep discharging. Deep discharging could damage the battery. Charge controller electronics is most sensitive and crucial to assuring stable PV system operation [19].

There are many different types of charge controllers available on the market, the simplest switch on/off regulators, PWM charge controllers which charge the battery with constant voltage or constant current (these are the most often used regulators in PV systems) and the most complex maximum power point tracking (MPPT) charge controller [19].

Charge controller functioning is characterized by two different voltage thresholds, battery and PV module voltage, upon which the battery is charged. At higher voltage, usually 12.5 V for 12 V batteries, charge controller switches the load to the battery, at lower voltage, typically 11.5 V, controller switches the load off. The controller adjusts the two voltage thresholds automatically according to the battery type [19].

Most controllers have two main modes of operation [14]:

- Normal operating condition, where the battery voltage varies between the acceptable maximum and minimum values.
- Over-charge or over-discharge condition, which occurs when the battery voltage reaches a critical value.

These second modes are obtained by using a switch with a hysteresis cycle, such as electromechanical or solid-state devices. The operation of a controller switch is shown in Fig. 6 [14].

3.3.3. *Inverters*

An inverter is used to convert the DC into AC. Various types of inverters are available, but not all are suitable for use when feeding power back into the mains supply. Therefore, the inverter designers should carefully specify the aim of usage.

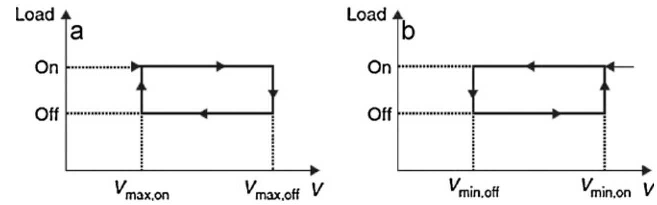

Fig. 6. Operating principle of over-charge and over-discharge protection [14]. (a) over-charge and (b) over-discharge.

PV inverters use special control for PV array, including MPPT and anti-islanding protection. PV inverters may be classified into three broad types:

- Stand-alone inverters are used in isolated systems where the inverter draws its DC energy from batteries charged by PV arrays and/or other sources, such as wind turbines, hydro turbines, or engine generators. Many stand-alone inverters also incorporate integral battery chargers to replenish the battery from an AC source, when available. Normally these do not interface in any way with the utility grid, and as such, are not required to have anti-islanding protection [20].
- Grid-tie inverters are designed to shut down automatically upon loss of utility supply, for safety reasons. They do not provide backup power during utility outages [20].
- Battery backup inverters are special inverters which are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid. These inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding protection [20].

3.4. *An example PV based system design of a home appliance*

In simple terms, there are two main types of PV systems for home appliances:

- A grid connected (also known as grid-tied) system (Table 1) provides for an interactive exchange of power between home system and the grid network.

  Electricity needs of a residential will be provided with solar energy using a system that includes PV panels (36 pcs of 156 mm × 156 mm multicrystalline PV cells) to approximately 20 units, inverters which will convert DC power produced by PV panels into AC power to be used by most of home appliances, an electric meter is a device that measures the amount of electrical energy consumed by a residence and control system panel.
- A stand-alone (also known as off-grid) system (Table 2) is which is not interconnected with the grid. It is mostly used in remote locations with no connection to the central grid system.

If the system has been establishment to move to the countryside, away from it all, off-grid PV panel system is suitable.

Table 1
Parameters for an example of grid-tied PV panel system.

Grid-tied PV panel system		
PV panel	$120\,W_p$, 21,82 V, 7,46 A	20×
Inverter-1	2000 W	2×
Inverter-2	1000 W	1×
Other	Electrical meter and control system panel	

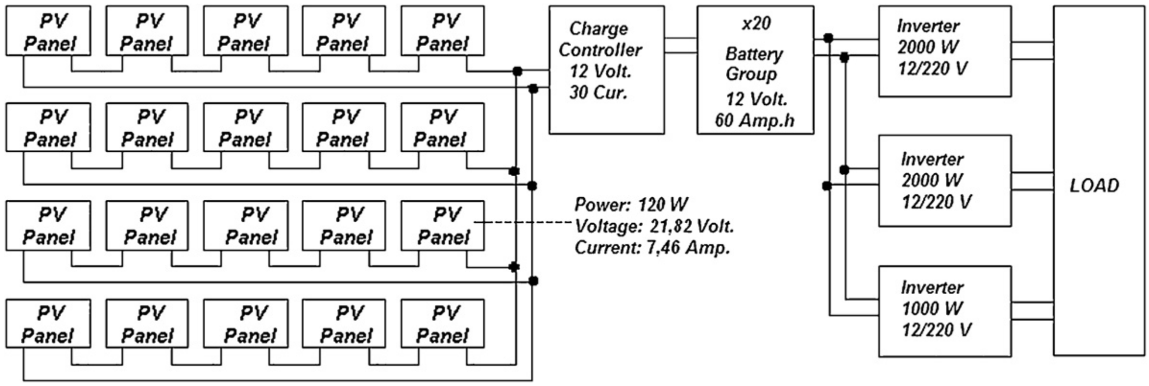

Fig. 7. Design of a 5 kW electrical power needs of a home with PV panels [21].

In the design procedure, 5 kW systems shown in Fig. 7, needed in current [21]:

$$I = \frac{P}{U \cdot \cos\varphi} = \frac{5000}{220.1} = 22.72 \quad (\cos\varphi = 1)$$

120 W_p watts of power to each module, the voltage is 21,82 and current is 7,46. If the serial and parallel connection of PV panels required by making use of current and voltage values can be obtained. Accordingly

The total power of PV panels:

$$P = 20 \cdot 120 = 2400\,\text{W} = 2.4\,\text{kW}$$

The current value is obtained:

$$I = 4 \cdot (7,46) = 29,84$$

The voltage value is obtained:

$$V = 5 \cdot (21,82) = 109,1$$

4. The factors affecting operating and efficiency of PV based electricity generation systems

4.1. Effects of PV technology types

Many types of PV cells are available today. This section gives details on the types of the PV cells that are currently in the manufacturing, research and development stage.

- *Monocrystalline silicon cells*: These cells are made from pure monocrystalline silicon. In these cells, the silicon has a single continuous crystal lattice structure with almost no defects or impurities. The main advantage of monocrystalline cells is their high efficiency, which is typically around 15%. The disadvantage of these cells is that a complicated manufacturing process is required to produce monocrystalline silicon, which results in slightly higher costs than those of other technologies [14]. Crystalline silicon cell technology is well established and the PV modules have long lifetimes (20 years or more) [22].
- *Multicrystalline silicon cells*: A less expensive material, multicrystalline silicon, by passes the expensive and energy-intensive crystal growth process. Multicrystalline cells are produced using numerous grains of monocrystalline silicon. In the manufacturing process, molten multicrystalline silicon is cast into ingots, which are subsequently cut into very thin wafers and assembled into complete cells. Multicrystalline cells are cheaper to produce than monocrystalline ones because of the simpler manufacturing process required. They are, however, slightly less efficient, with average efficiencies being around 12% [14,22].
- *Amorphous silicon cells*: Generally, the main difference between these cells and the previous ones mentioned above is that, instead of the crystalline structure, amorphous silicon cells are composed of silicon atoms in a thin homogenous layer. Additionally, amorphous silicon absorbs light more effectively than crystalline silicon, which leads to thinner cells, also known as a thin film PV technology. Thin film solar has approximately 15% market share; the other 85% is crystalline silicon [23]. The greatest advantage of these cells is that amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible. Their disadvantage is the low efficiency, which is on the order of 6% [14].
- *Other types of cells*: In addition to the above types, a number of other promising materials, such as CdTe and CuInSe2, are used today for PV cells. The main trends today concern the use of polymer and organic PV cells. The attraction of these technologies is that they potentially offer fast production at low cost in comparison to crystalline silicon technologies, yet they typically have lower efficiencies (around 4%), and despite the demonstration of operational lifetimes and dark stabilities under inert conditions for thousands of hours, they suffer from stability and degradation problems [14]. Each semiconducting material has its own properties which make it more or less suitable for use in a PV cell. One of these properties is the so-called band gap, which is the energy gap an electron must cross in order to be promoted from the valence band to the conduction band [24]. In the literature studies [22], it has been shown that silicon, with its bandgap of 1.12 eV, is not optimal. Materials with bandgaps nearer to 1.5 eV, such as GaAs and CdTe, have higher theoretical efficiencies [22]. Maximum limiting efficiency is found by considering all of these factors show that Fig. 8.

Table 2
Parameters for an example of off-grid PV panel system.

Off-grid PV panel system		
PV panel	120 W_p, 21,82 V, 7,46 A	20×
Inverter-1	2000 W	2×
Inverter-2	1000 W	1×
Battery	12 V, 60 Ah	20×
Charge Regulator	30 A, 12 V	1×

As mentioned above, a single-material PV cell can convert only about 15% of the available energy to useful electrical power. To improve this performance, multiple cells with different band gaps, which are more complex and therefore more expensive, can be used. These are called multi-junction PVs. Particularly; a

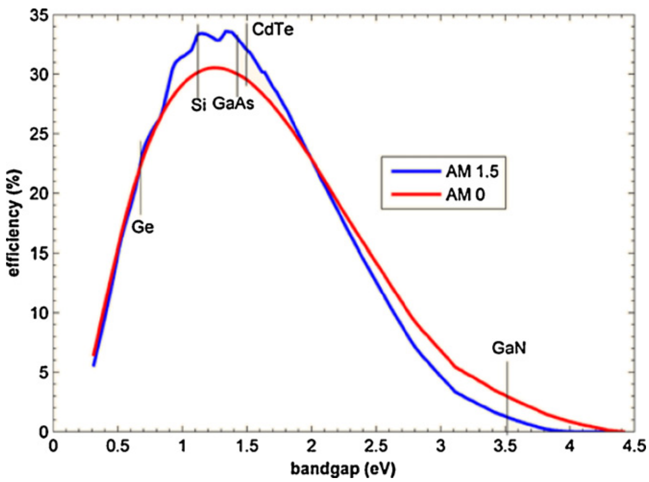

Fig. 8. Relationship between bandgap and efficiency for PV cells [38].

triple-junction PV produced recently achieved a remarkable 40% efficiency. This PV consists of three layers of PV material placed one atop the other. Each of the three materials captures a separate portion of the solar spectrum and the objective is to capture as much of the solar spectrum as possible. These are much more expensive than other silicon PV cells, but their efficiency offsets their high cost, and in concentrating systems, a small area of these cells is required [14].

Another way to increase the effectiveness of PVs according to their technology is to concentrate sunlight on small, highly efficient PV cells using inexpensive reflective material, lenses, or mirrors. These are known as concentrating photovoltaics (CPVs). Today, the technology takes up a very small portion of the solar industry; however, it is expected that the CPV industry will soon take up a larger share of the solar market as technology improves and cost comes down [14].

4.2. Effects of ambient conditions

There are various ambient conditions that affect the output of a PV power system. These factors should be taken into consideration so that the customer has realistic expectations of overall system output.

Module temperature is a parameter that has great influence in the behavior of a PV system, as it modifies system efficiency and output energy. In addition to this, the atmospheric parameters such as irradiance level, ambient temperature, wind speed, dirt/dust and the particular installing conditions have influence, too.

Temperature effects are the result of an connatural characteristic of crystalline silicon cell-based modules. They tend to produce higher voltage as the temperature drops and, conversely, to lose voltage in high temperatures. Any PV module or system derating calculation must include adjustment for the temperature effect [25,26].

As temperature increases, the band gap of the semiconductor shrinks, and the open circuit voltage Voc decreases following the p–n junction voltage temperature dependency of seen in the diode factor q/kT. PV cells therefore have a negative temperature coefficient of $V_{OC}(\beta)$. Moreover, a lower output power results given the same photocurrent I_{PH} because the charge carriers are liberated at a lower potential [27].

As temperature increases, again the band gap of the intrinsic semiconductor shrinks meaning more incident energy is absorbed because a greater percentage of the incident light has enough energy to raise charge carriers from the valence band to the conduction band. A larger photocurrent results; therefore, I_{SC} increases for a given insulation, and PV cells have a positive temperature coefficient of $I_{SC}(\alpha)$ [27]. This effect would raise the theoretical maximum power by the relationship below (4):

$$P_{\max} = I_{SC} \times V_{OC} \tag{4}$$

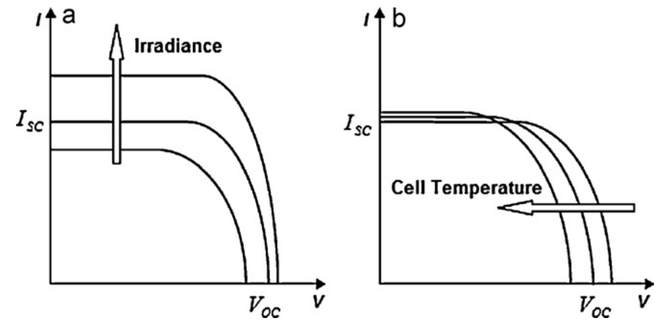

Fig. 9. Effects of irradiation and cell temperature on PV cell characteristic (a) effect of increased irradiance and (b) effect of increased cell temperature [14].

The influences of temperature and irradiance on the cell characteristics are shown in Fig. 9. As seen from Fig. 9(a), the open circuit voltage increases logarithmically by increasing the solar radiation, whereas the short circuit current increases linearly. The influence of the cell temperature on the cell characteristics is shown in Fig. 9(b). The main effect of the increase in cell temperature is on open circuit voltage, which decreases linearly with the cell temperature; thus the cell efficiency drops. As can be seen, the short circuit current increases slightly with the increase of the cell temperature [14].

The procedure to determine the normal operating cell temperature (*NOCT*) of a PV module included in the IEC standards [28,29] is based on the fact that the difference between the module temperature T_m and the ambient temperature T_{amb} can be considered independent of the ambient temperature and linearly proportional to the irradiance at levels above 400 W/m^2. An example of application of *NOCT* determination is the calculation of module temperature from ambient temperature, available solar irradiance and *NOCT* following the known equation [30]:

$$T_m = T_{amb} + (NOCT - 20)\frac{E}{800} \tag{5}$$

where E the irradiance in W/m^2.

A PV cell's energy conversion efficiency (η, "eta"), is the percentage of power converted (from absorbed light to electrical energy) and collected, when a PV cell is connected to an electrical circuit. This term is calculated using the ratio of the maximum power point, $P_{\max}$, divided by the input light irradiance (E, in W/m^2) under standard test conditions and the surface area of the PV cell (A_C in m^2) [31]:

$$\eta = \frac{P_{\max}}{EA_c} \tag{6}$$

The efficiencies in a PV module are decreased with increasing the module temperature T_m. The variation of a sample PV module [32] efficiency η with the module temperature T_m f is given by the characteristic in Fig. 10.

An effective way of improving efficiency and reducing the rate of thermal degradation of a PV module is by reducing the operating temperature of its surface. This can be achieved by cooling the module and reducing the heat stored inside the PV cells during operation. As an example, solar-water pumping system can be given. Such a system consists of a PV module cooled by water, a water pump, and a water storage tank. Cooling of the PV module is achieved by introducing water trickling configuration on the upper surface of the module. The results [33] indicated that due to the

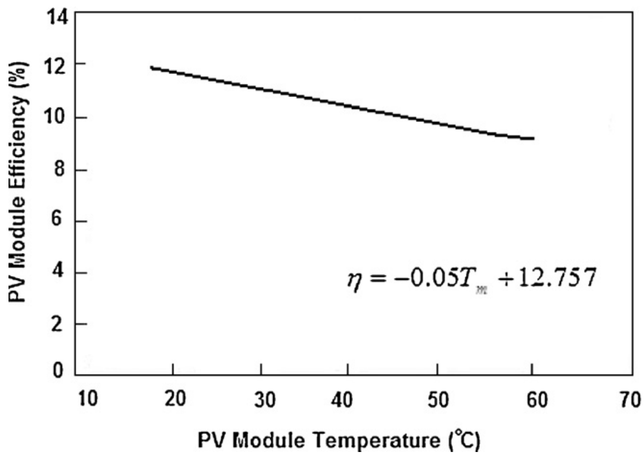

Fig. 10. Relationship of the PV module efficiency (η) and PV module temperature (T_m) [32].

heat loss by convection between cooling water and the PV module's upper surface, an increase of about 15% in system output is achieved at peak solar irradiation conditions. And also the results of such a system's indicated that an increase of 5% in delivered energy from the PV module can be achieved during dry and warm seasons.

Another important factor is dirt/dust. Dirt/dust can accumulate on the PV module surface, blocking some of the sunlight and reducing output. Although typical dirt/dust is cleaned off during every rainy season, it is more realistic to estimate system output taking into account the reduction due to dust buildup in the dry season. So the "100 W module" operating with some accumulated dirt/dust may operate on average at about 79 W [33]:

- A manufacturer may rate a particular PV module output at 100 W of power under standard test conditions, and call the product a "100 W PV module." This module will often have a production tolerance of ±5% of the rating, which means that the module can produce 100 W × 0.95 = 95 W.
- Output power of the PV module reduces as module temperature increases. When operating on a roof, a PV module will heat up substantially, reaching inner temperatures of 50–75 °C. For crystalline modules, a typical temperature reduction factor recommended by the CEC is 89% or 0.89. So the "100-W module will typically operate at about 95 W × 0.89 = 85 W under full sunlight conditions.
- A typical annual dust reduction factor to use is 93% or 0.93. A "100-W module," may operate on average at about 85 W × 0.93 = 79 W.

4.3. Effects of system equipments

4.3.1. Battery and charge control

The major parameters that are important for efficiency of PV batteries are types of batteries, capacity of batteries, maximum charge currents, temperatures and manufacturer tolerances [34].

The selection of battery type and size depends mainly on the load and availability requirements. When batteries are used in a PV system, they must be located in an area without extreme temperatures, and the space where the batteries are located must be adequately ventilated. However, for more capacity, batteries can be arranged in parallel [5].

Batteries are classified by their nominal capacity, which is the number of ampere hours (Ah) that can be maximally extracted from the battery under predetermined discharge conditions. The efficiency of a battery is the ratio of the charge extracted (Ah) during discharge divided by the amount of charge (Ah) needed to restore the initial state of charge. Therefore, the efficiency depends on the state of charge and the charging and discharging current [14].

The energy produced during the day, which was not consumed by loads, is saved in batteries. Saved energy can be used at night or during the days with bad weather conditions. Batteries in PV systems are often charged/discharged; therefore, they must meet stronger requirements than regular batteries. Regular batteries are not suitable for PV systems. There are many PV battery types available in the market. Most often used classic Pb acid batteries are produced especially for PV systems, where deep discharge is required. Other battery types, such as NiCd or NiMH are rarely used, unless in portable devices. Hermetical batteries often consist of electrolyte in gel form. Such batteries do not require maintenance. Deep-cycle lead-acid batteries can be flooded or valve-regulated batteries are commercially available in a variety of sizes. Flooded (or wet) batteries require greater maintenance but, with proper care, can last longer, whereas valve-regulated batteries require less maintenance [19].

Typical PV system batteries lifetime spans from 3 to 5 years, depending heavily on charging/discharging cycles, temperature and other parameters. The PV batteries prices are higher than the prices of classic car batteries, yet their advantages are longer lifetime and lower discharging rates. Consequently, the maintenance costs of the PV system are lower [19].

Normally, charge controllers allow the battery voltage to determine the operating voltage of a PV system. However, the battery voltage may not be the optimum PV operating voltage. Some controllers can optimize the operating voltage of the PV modules independently of the battery voltage so that the PV operates at its maximum power point [14].

4.3.2. Inverters

A power electronics based inverter is used to convert the DC into AC electricity. The structure of the inverter can be single or three phase. Some inverters have good surge capacity for starting motors, others have limited surge capacity. The PV system designer should specify both the type and size of the load the inverter is intended to service.

The inverter is characterized by a power conversion efficiency η_{inv} [14]. Besides changing the DC into AC, the main task of the inverter is to keep a constant voltage on the AC side and convert the input power P_{in}, into the output power P_{out} with the possible highest efficiency, given by (7):

$$\eta_{inv} = \frac{P_{out}}{P_{in}} = \frac{V_{ac} I_{ac} \cos(\alpha)}{V_{dc} I_{dc}} \quad (7)$$

where $\cos(\alpha)$ is power factor; I_{dc} is current required by the inverter from the DC side; V_{dc} is input voltage for the inverter from the DC side.

Numerous types of inverters such as line commutated and self-commutated (voltage source or current source) are available, but not all are suitable for use when feeding power back into the network as in PV grid-connected PV system.

In a grid-connected PV system, if the power conversion efficiency of the inverter η_{inv} is too small, the power generated by the PV array cannot be output to the AC utility system effectively. It is thus necessary to increase the conversion efficiency as high as possible. To improve efficiency, it is important to use sophisticated circuit technology, for example, to reduce conduction losses of semiconductor switching devices and losses caused by switching, and reduce losses caused by cables. Some inverters had been less efficient, but efficiency has been improved in recent years [35].

It is also important to grasp the installation environment of the inverter for the PV power system, and to take into consideration the influence of the inverter on the surrounding environment. The most important installation conditions of the inverter are the

ambient temperature condition, the requirements for waterproofness and dustproofness, actual audible noise level of the inverter, and applicable regulations for power quality (or electro-magnetic compatibility) [35].

4.4. Power quality requirement for the grid connected PV systems

One of the most important technical issues of the grid connection of local power generation is the power quality, because most of the equipments can experience severe problems such as data losses, malfunction, control errors, when the power supply has low power quality. For any grid connected PV system, power factor and harmonic considerations are important. The local PV based electric power producers must follow the utility requirements of main grid interfacing. Some of the main grid interface criteria that should be checked with the utility are as follows [36]:

- Harmonic distortion.
- Power factor correction.
- Voltage and frequency regulation.
- Protection and operation criteria.
- Adequate safeguard against islanding.

The harmonic distortion can be defined as that particular disturbance that, originated by the presence of non-linear components in the electrical systems, determines a permanent modification of the voltage and current sinusoidal wave shapes, in terms of sinusoidal components at a frequency different from the fundamental frequency. PV generators are connected to the distribution network through power electronics based inverters and are therefore potentially able to cause harmonics, so downgrading the quality of electricity and altering the performances of other equipment sensitive to harmonics. On the other hand, the inverters themselves are sensitive to harmonics and may operate incorrectly as a result of the harmonic distortion [37].

It should be noted that; the power quality and availability of a grid connected PV system is determined by its power conditioning units. The power conditioning units must provide DC to AC conversion, peak power tracking and protection, effectively. Recent research studies have proven that the use of multilevel PWM inverter modules employing IGBTs as the power conditioners has the following advantage: they can be applied to reach high voltages with low harmonic distortion without the use of transformers [36].

5. Discussions and conclusions

One of the most popular applications of renewable energy technology is the installation of PV systems using sunlight to generate electrical power. In this paper, a detailed overview of the factors that affecting the operation and efficiency of PV based electricity generation systems was presented. Main topics for these factors are PV cell technology, ambient conditions and selected equipment.

According to detailed overview presented in this paper, the following major conclusions can be summarized:

- Many types of PV cells are available today such as monocrystalline, multicrystalline, multi-junction and concentrating. The main advantage of monocrystalline cells is their high efficiency, but the disadvantage of these cells is that a complicated process is required to produce monocrystalline silicon. Multicrystalline cells are cheaper to produce than monocrystalline types because of the simpler manufacturing process required. However, they are slightly less efficient. As mentioned above, a single-material PV cell has only about 15% efficiency. To improve this performance up to 40%, multi-junction cells with different band gaps can be used, but this technology is more complex and more expensive. However, another way to increase the efficiency is to concentrate sunlight on PV cells using inexpensive reflective material such as lenses, or mirrors.
- There are various ambient conditions such as irradiance, temperature and dirt/dust that affect the output of a PV power system. The open circuit voltage increases logarithmically by increasing the solar radiation, whereas the short circuit current increases linearly and thus, the output power increases. However, the main effect of the increase in cell temperature is on open circuit voltage, which decreases with the cell temperature. The short circuit current increases slightly with the increase of the cell temperature, thus the cell efficiency drops. An effective way of improving efficiency of a PV module is by reducing the operating temperature of its surface. This can be achieved by cooling the module and reducing the heat stored inside the PV cells during operation. Another important ambient factor is dirt/dust. Dirt/dust can accumulate on the PV module surface, blocking some of the sunlight and reducing efficiency.
- The selection and design of required equipment such as batteries, chargers, power electronic devices and wiring are also vital for the efficiency and operation of the PV systems. Batteries of PV systems are often charged/discharged. Therefore, they must meet stronger requirements than regular batteries. Flooded batteries require greater maintenance, but can last longer. However, valve-regulated batteries require less maintenance but last shorter. Numerous types of inverters are available, but not all are suitable for PV systems. If the power conversion efficiency of the PV inverter is small, the power generated by the PV array cannot be output to the utility system effectively. To improve the power conversion efficiency of PV inverter, it is important to use well-designed circuit technology, for example, to reduce conduction and switching losses of semiconductor devices and to reduce losses caused by connection cables.
- Another important issue that should be taken into account for the grid connection of local PV power generation is the quality of power (especially reducing the problems caused by of harmonics and low power factor), because most of the equipments can experience severe problems and economical losses when the power supply has low power quality.

References

[1] Hossain E, Muhida R, Ali A. Efficiency improvement of solar cell using compound parabolic concentrator and sun tracking system. In: EPEC Electric Power Conference. 2008. p. 1–8.

[2] http://www.pvupscale.org/IMG/pdf/D5.3_Study_on_global_context_environmental_costs_and_ energy _portfolio_analysis_of_urban_PV. pdf; 2010 [accessed January 2010].

[3] http://www.ren21.net/globalstatusreport/g2009.asp; 2010 [accessed January 2010].

[4] http://www.azooptics.com/Details.asp?NewsID=3813; 2010 [accessed January 2010].

[5] García JO, Gago EJ, Bayo JA, Montes GM. The use of solar energy in the buildings construction sector in Spain. Renewable and Sustainable Energy Reviews 2007;11(December (9)):2166–78.

[6] http://www.epia.org/policy/national-policies/germany/german-pv-market.html; 2010 [accessed January 2010].

[7] Ispre report: research and development on renewable energies: a global report on photovoltaic and wind energy. Paris: International Science Panel on Renewable Energies; 2009. p. 1–44.

[8] http://www.solarbuzz.com/Marketbuzz2009-intro.htm; 2010 [accessed February 2010].

[9] Zhang X, Ruoshui W, Molin H, Martinot E. A study of the role played by renewable energies in China's sustainable energy supply. Elsevier Energy 2010;35:4392–9.

[10] Liu LQ, Wang ZX, Zhang HQ, Xue YC. Solar energy development in China—a review. Renewable and Sustainable Energy Reviews 2010;14(January (1)):301–11.

[11] Liu LQ, Wang ZX. The development and application practice of wind-solar energy hybrid generation systems in China. Renewable and Sustainable Energy Reviews 2009;13(August–September (6–7)):1504–12.

[12] Li DHW, Cheung GHW, Lam JC. Analysis of the operational performance and Efficiency characteristic for photovoltaic system in Hong Kong. Energy Conversion and Management 2005;46(May (7–8)):1107–18.
[13] http://en.wikipedia.org/wiki/Photovoltaic_module; 2010 [accessed January 2010].
[14] Kalogirou S. Solar energy engineering: processes and systems: chapter 9. Academic Press; 2009. p. 469–517.
[15] http://www.esdalcollege.nl/eos/vakken/na/zonnecel.htm; 2010 [accessed January 2010].
[16] Pearsall NM, Hill R. Clean electricity from photovoltaics: chapter 15. Imperial College Press; 2001. pp. 1–42.
[17] Hansen AD, Sorensen P, Hansen LH, Bindner H. Models for a stand alone PV system. Roskilde: Riso National Laboratory; 2000. p. 1–78.
[18] http://www.solardirect.com/pv/batteries/batteries.htm; 2010 [accessed February 2010].
[19] http://www.pvresources.com/en/chargereg.php; 2010 [accessed January 2010].
[20] http://en.wikipedia.org/wiki/Pv_inverter; 2010 [accessed February 2010].
[21] Dinçadam F. The practice of the systems obtaining hot water via solar cell, enlightening the street and following the sun. M.Sc. thesis, Engineering Electrical and Electronics University of Yuzuncu Yil; 2008.
[22] Çapar Ş. Photovoltaic power generation for polycrystalline solar cells and turning sunlight into electricity. M.Sc. thesis, Engineering Physics University of Gaziantep; July 2005.
[23] http://en.wikipedia.org/wiki/Solar_cell#Thin-film_solar_cells; 2010 [accessed February 2010].
[24] http://www.solarpower2day.net/solar-cells; 2010 [accessed February 2010].
[25] http://www.altestore.com/howto/Solar-Power-Residential-Mobile-PV/Off-Grid-Solar-Systems/Electrical-Characteristics-of-Solar-Panels-PV-Modules/a87/; 2010 [accessed February 2010].
[26] Krauter S. Increased electrical yield via water flow over the front of photovoltaic panels. Solar Energy Materials and Solar Cells 2004;82:13–37.
[27] Shenck NS. Alternative energy systems. U.S. Naval Academy Lecture Readings; 2010.
[28] IEC 61215: Crystalline silicon terrestrial photovoltaic (PV) modules—design qualification and type approval; 2005.
[29] IEC 61646: Thin-film terrestrial photovoltaic (PV) modules—design qualification and type approval; 2008.
[30] Garcia MCA, Balenzategui JL. Estimation of photovoltaic module yearly temperature and performance based on nominal operation cell temperature calculations. Renewable Energy 2004;29(October (12)):1997–2010.
[31] http://en.wikipedia.org/wiki/Solar_cell; 2010 [accessed February 2010].
[32] Yamaguchi T, Kawakami M, Kitano K, Nakagawa S, Tokoro T, Nakano T, et al. Data analysis on performance of PV system installed in south and north directions. In: 3rd world conference on photovoltaic energy conversion. 2003. p. 2239–42.
[33] Endecon Engineering: Energy technology development division, consultant report, a guide to photovoltaic (PV) system design and installation. California Energy Commission; 2001. p. 1–40.
[34] Özgöçmen A. Electricity generation using solar cells. M.Sc. thesis, Gazi University Institute of Science and Technology, Ankara; May 2007.
[35] Ishikawa T. Grid connected photovoltaic power systems: survey of inverter and related protection equipments. Task V Grid Interconnection of Building Integrated And Other Dispersed Photovoltaic Power Systems; 2002, p.1–64.
[36] Tennakoon SM, Keerthipala WWL, Lawrance WB. Solar energy for development of a cost-effective building energy system. In: Proceedings of the PowerCon, vol. 1. 2000. p. 55–9.
[37] Verhoeven B. Utility aspects of grid connected photovoltaic power systems. International Energy Agency Implementing Agreement on Photovoltaic Power Systems, Task V Grid Interconnection of Building Integrated And Other Dispersed Photovoltaic Power Systems; 1998. p. 1–168.
[38] Turan R. "Physics and Technology of Solar Cells," Güneş GözelerininFiziği ve Teknolojisi 19 Mayıs Lisansüstü Fizik Yaz Okulları Sunumu, 17–21, May 2010, pp. 1–26.